Full one-loop electroweak radiative corrections to single photon production in e^+e^-

ACAT03, Tsukuba, 4 Dec. 2003

LAPTH and Minamitateya Collaboration

presented by K.Kato

Motivation

- Higgs and SUSY study at future colliders
- Detailed, high-accuracy prediction required for discovery/(major) background channels
- EW radiative corrections for multi-body channels … huge computation
- Automation of perturbative computation … essential tool for HEP

2→3 in ee

$e^+e^- \to \nu\bar{\nu}H$

GRACE, hep-ph/0212261
Denner etal., hep-ph/0302198

$e^+e^- \to t\bar{t}H$

GRACE, hep-ph/0307029
You et al., hep-ph/0306036
Denner etal., hep-ph/0307193

$e^+e^- \to ZHH$

GRACE, hep-ph/030910
Zhang etal., hep-ph/0308203

New results

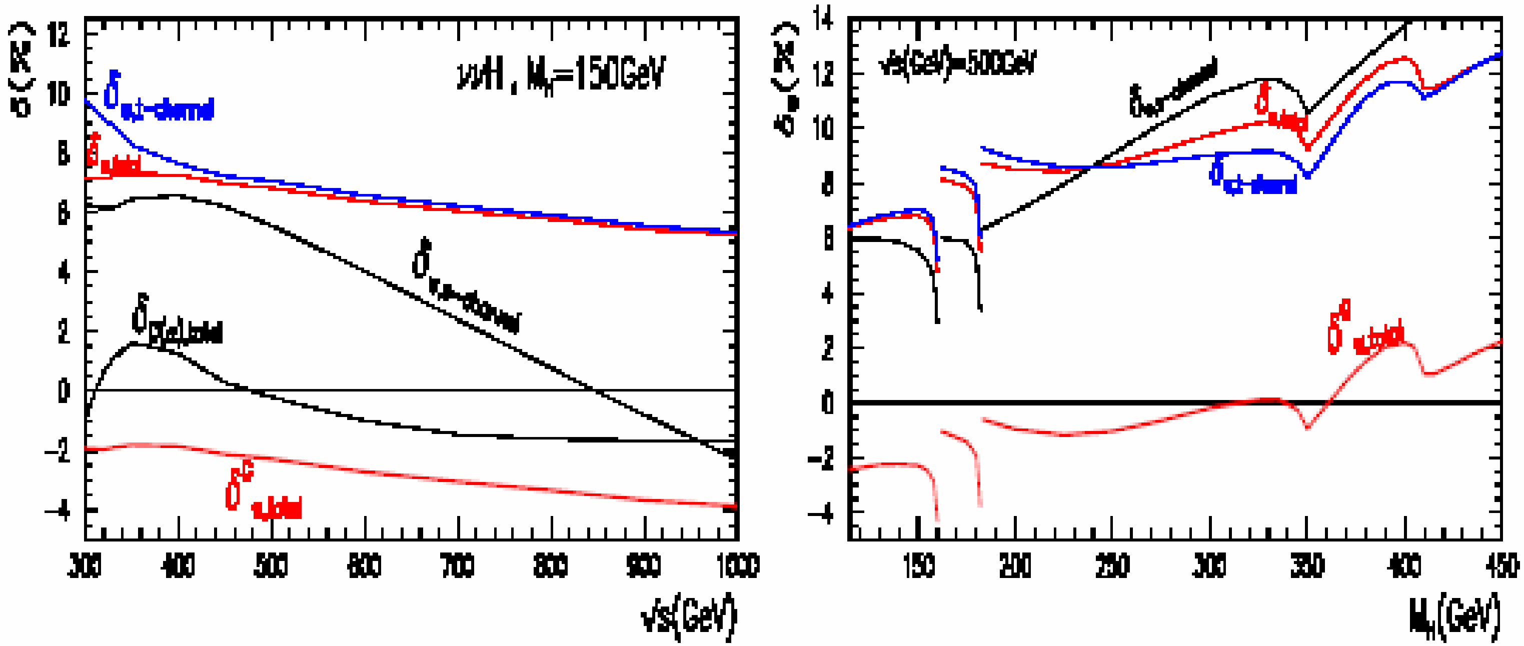
$e^+e^- \to e^+e^-H$

$e^+e^- \to \nu\bar{\nu}\gamma$

$\nu = \nu_\mu, \nu_e$

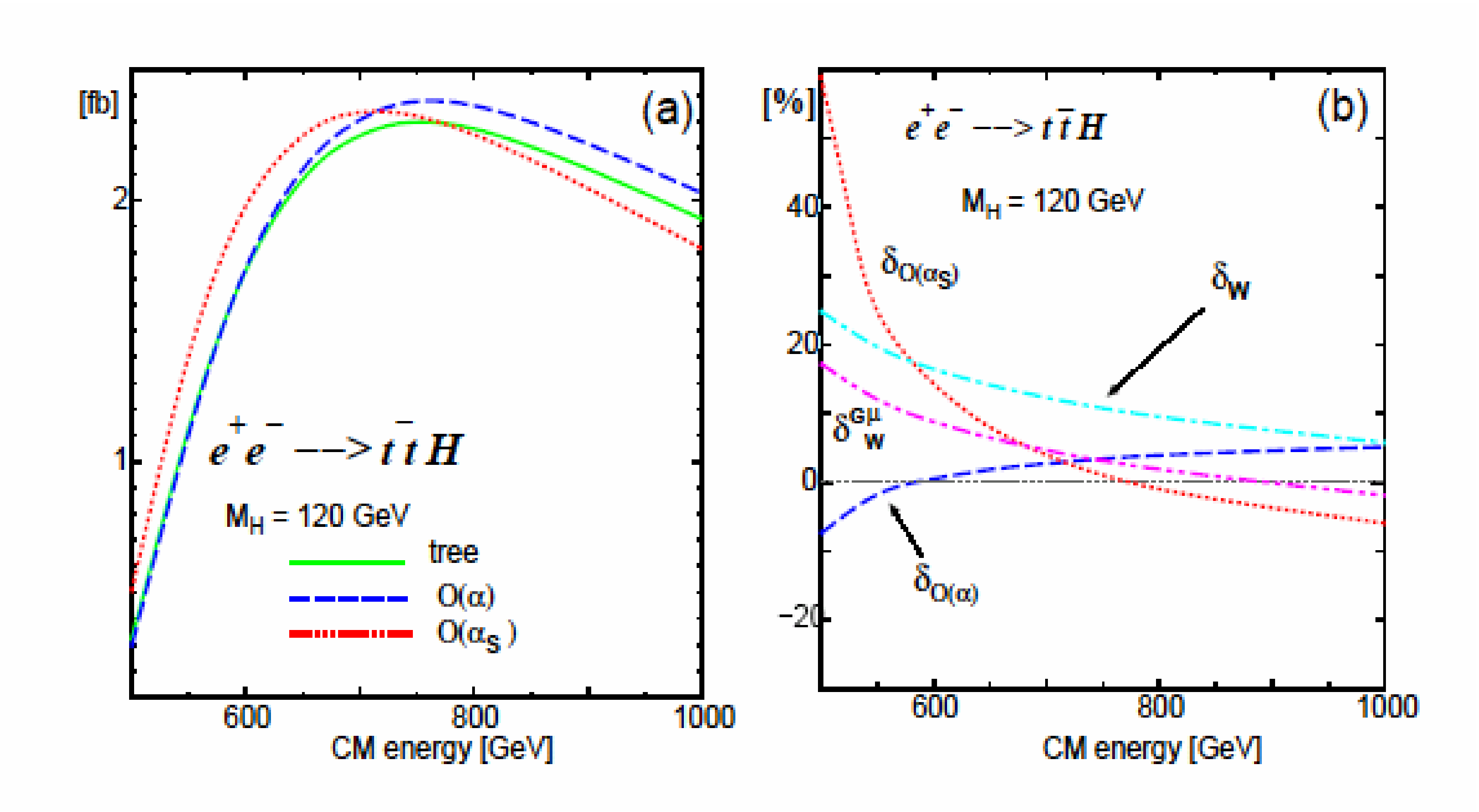
$$e^+e^- \to \nu\bar{\nu}H$$

hep-ph/0212261
Phys.Lett.B 559(2003) 252.



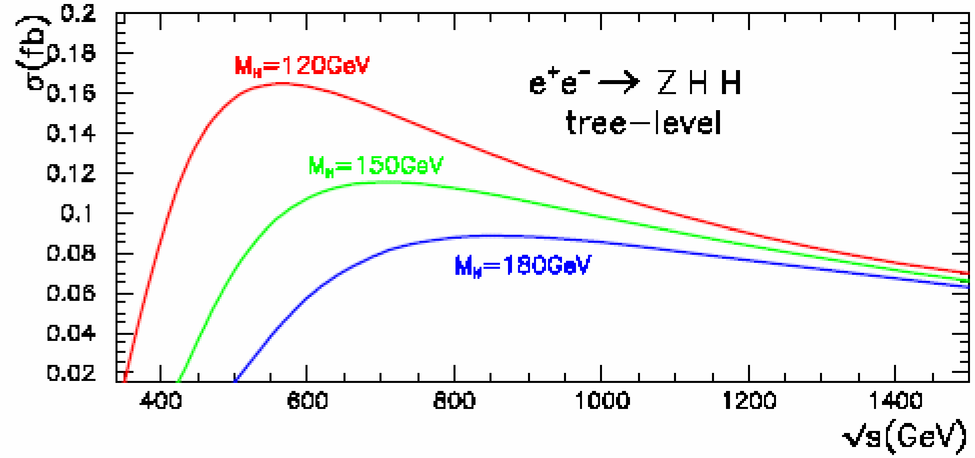
$$e^+e^- \to t\bar{t}H$$

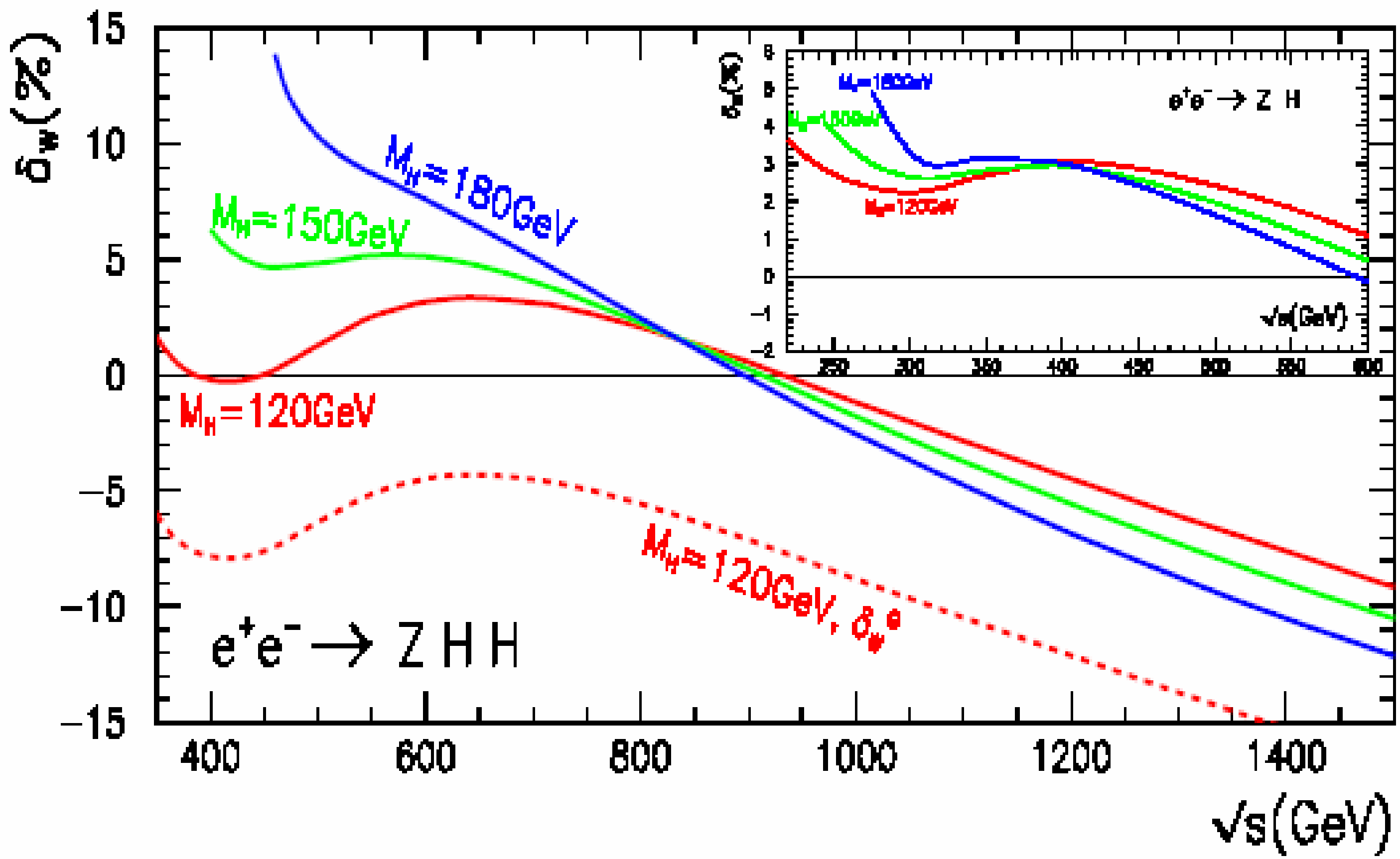
hep-ph/0307029
Phys.Lett.B 571(2003) 163.



$e^{+}e^{-} \to ZHH$

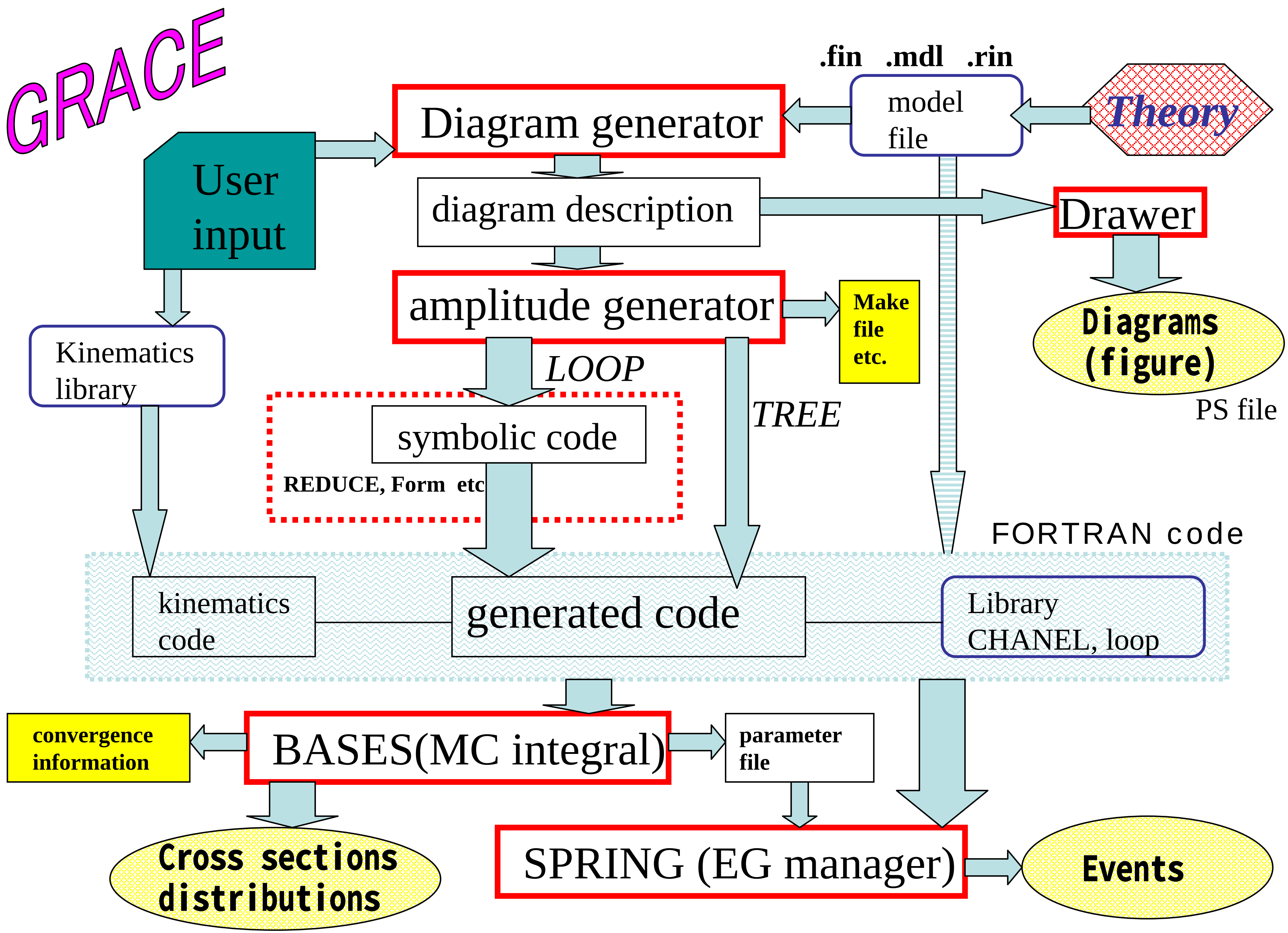
hep-ph/030910
Phys.Lett.B 576(2003)152.





system components

- Diagram generation for input process
- Amplitude/Matrix element generation
- Kinematics and Integration (efficiency)
- Event generation (efficiency & weight)
- Peripheral tools: rule generator, diagram selection, QED radiation, PDF, loop integral library, multi-process, color flow and interface for hadronization, etc.


GRACE
.fin .mdl .rin
Theory
model file
Diagram generator
User input
diagram description
Drawer
amplitude generator
Make file etc.
Diagrams (figure)
PS file
Kinematics library
LOOP
TREE
symbolic code
REDUCE, Form etc
FORTRAN code
kinematics code
generated code
Library CHANEL, loop
convergence information
BASES(MC integral)
parameter file
Cross sections distributions
SPRING (EG manager)
Events

Diagnostics

- How you can believe the numbers an automated system has produced?

- UV finiteness
- IR finiteness
- gauge invariance

Non-linear gauge

- Check by gauge invariance in 1-loop
  Independence on several gauge parameters

$$\tilde{\alpha}, \tilde{\beta}, \tilde{\delta}, \tilde{\varepsilon}, \tilde{\kappa}$$

- Numerator structure is the same as Feynman gauge
- Vertices modified
- New vertices (ghost sector) appear

$$g^{\mu\nu} \quad (\text{for } \xi = 1)$$

$$\tilde{\alpha} = 1 \Rightarrow \text{no AW}\chi$$

Non-linear gauge fixing terms

$$L_{GF} = -\frac{1}{\xi_W} F^+ F^- - \frac{1}{2\xi_Z}\left(F^Z\right)^2 - \frac{1}{2\xi}\left(F^A\right)^2$$

$$F^{\pm} = \left(\partial^{\mu} \mp ie\tilde{\alpha}A^{\mu} \mp i\frac{ec_W}{s_W}\tilde{\beta}Z^{\mu}\right)W_{\mu}^{\pm} \qquad F^A = \partial^{\mu}A_{\mu}$$

$$+\xi_W\left(M_W\chi^{\pm} + \frac{e}{2s_W}\tilde{\delta}H\chi^{\pm} \pm i\frac{e}{2s_W}\tilde{\kappa}\chi_3\chi^{\pm}\right)$$

$$F^Z = \partial^{\mu}Z_{\mu} + \xi_Z\left(M_W\chi_3 + \frac{e}{2s_W c_W}\tilde{\varepsilon}H\chi_3\right)$$

Samples of NLG Feynman rules

$$W - W - A$$

$$e[g^{\mu\nu}(p_1 - p_2)^\rho + (1 + \tilde{\alpha}/\xi_W)(p_3^\nu g^{\mu\rho} - p_3^\mu g^{\nu\rho}) + (1 + \tilde{\alpha}/\xi_W)(p_2^\mu g^{\nu\rho} - p_1^\nu g^{\mu\rho})]$$

$$W - \chi - A$$

$$\mp ieM_W(1 - \tilde{\alpha})g^{\mu\nu}$$

modified

$$\bar{c}^{\mp} - c^A - A - W^{\pm}$$

$$-e^2\tilde{\alpha}g^{\mu\nu}$$

$$\bar{c}^{\mp} - c^A - \chi^{\pm} - H$$

$$\mp ie^2 \frac{1}{2s_W}\tilde{\delta}\xi_W$$

ghost-ghost- vector-vector / ghost-ghost-scalar-scalar

5-point functions

N rank M

$$I_5 = \sum G_{\mu\nu\cdots\sigma} \int d\ell \, \frac{\ell^\mu \ell^\nu \cdots \ell^\sigma}{D_0 D_1 D_2 D_3 D_4}$$

$$D_0 = \ell^2 + X_0$$

$$D_j = \ell^2 + 2\ell \cdot r_j + X_j$$

$$A_{ij} = r_i \cdot r_j \qquad g^{\mu\nu} = r_i^\mu A_{ij}^{-1} r_j^\nu \qquad \ell^2 = D_0 - X_0$$

$$\ell^\mu = r_i^\mu A_{ij}^{-1}(r_j^\nu \ell) = \tfrac{1}{2} r_i^\mu A_{ij}^{-1}[D_j - D_0 + X_0 - X_j]$$

$$\Rightarrow \quad N = \sum_{\alpha=}^{4} E_\alpha(\ell) D_\alpha + F \qquad 1 = \sum_{\alpha=0}^{4} [a_\alpha + b_{\alpha j}(\ell r_j)] D_\alpha$$

drop

scalar 5-pnt

BOX

BOX rank M-1

$\boldsymbol{\delta}$ (QED), $\boldsymbol{\delta}$ (EW)

$$\sigma = \sigma_0 (1 + \delta_{QED} + \delta_W)$$

δ_W non-QED virtual corrections

$$\delta_{QED} = \delta_{QED}^{V} + \delta_{QED}^{soft} + \delta_{QED}^{hard}$$

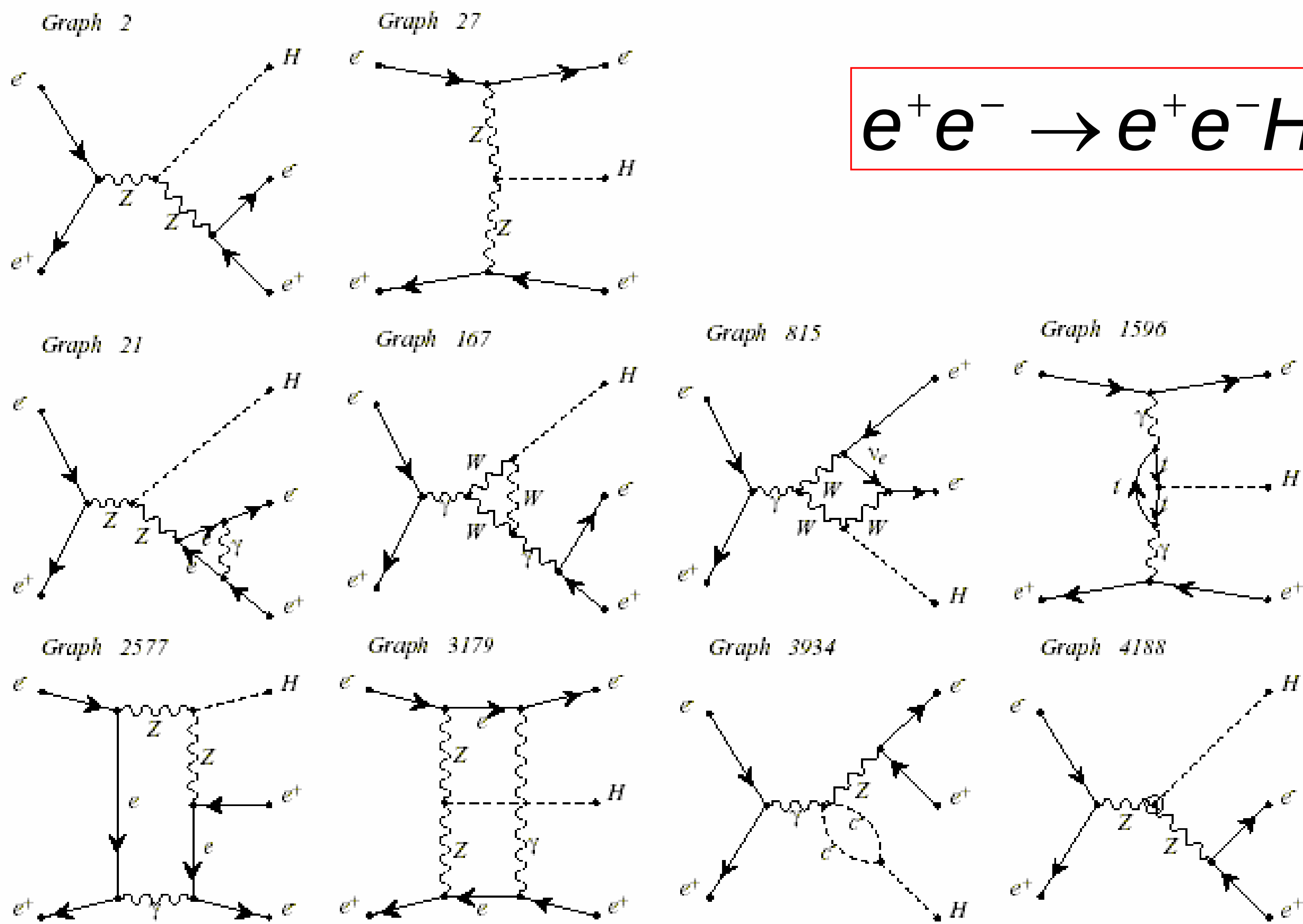
phase space subtraction f_{LL} =radiator

$$\delta_{QED} = \int \left(d\sigma_0 \delta_{QED}^{v} + d\tilde{\sigma}_0 \otimes f_{LL} \right) + \int_{hard} \left(d\sigma_{1\gamma} - d\tilde{\sigma}_0 \otimes f_{LL} \right)$$

ee→eeH

- diagrams
  full set (for NLG check)
  tree 42, 1-loop 4470 (inc. C.T.)
  production set (for integration)
  tree 2, 1-loop 510 (inc. C.T.)
- M_W= 80.3766 GeV , M_Z= 91.1876 GeV
  Γ_Z= 2.4956 GeV (appear at resonant poles only)
  M_H= 120GeV, m_t = 174GeV
  E_{CM}= 200 〜 3000 GeV, kcut=E*0.05

$$e^+e^- \rightarrow e^+e^-H$$



check by NLG (ee→eeH)

compute for several **ξ**, at a point in PS

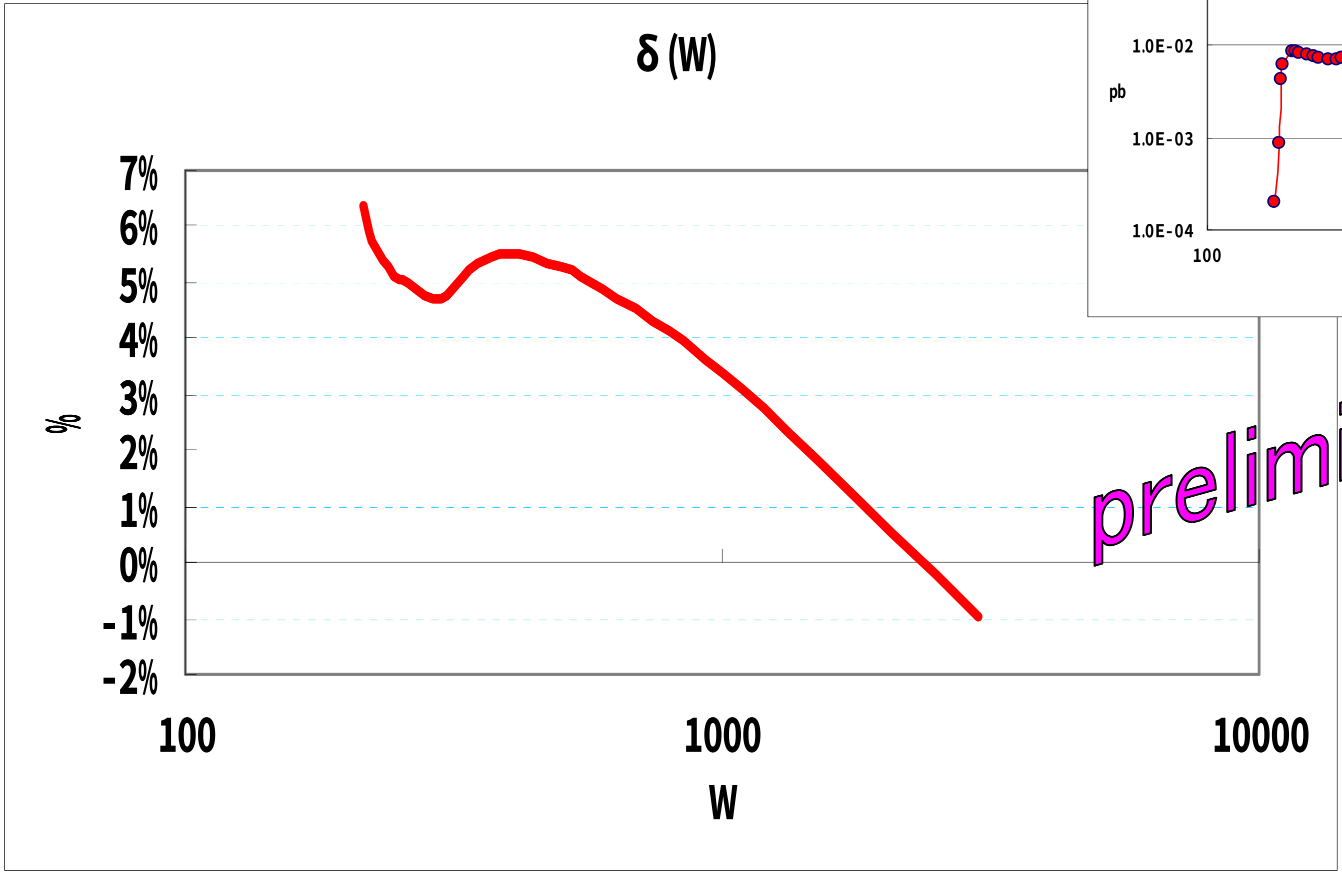
$$f = \sum_{k=0}^{4} a_k \xi^k \quad (\xi = \tilde{\alpha}, \tilde{\beta}, \tilde{\delta}, \tilde{\varepsilon}, \tilde{\kappa})$$

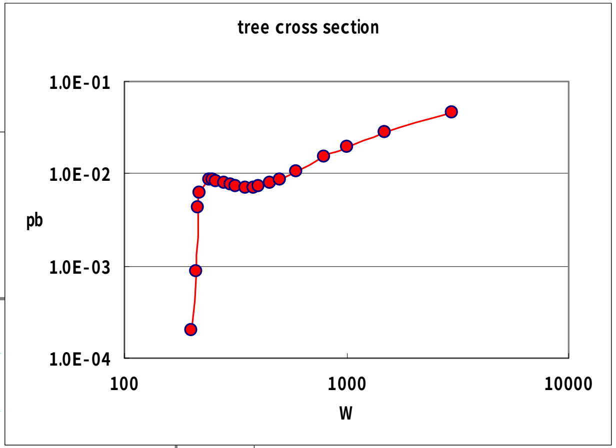
$\tilde{\alpha}$

	a^4	a^3	a^2	a^1	a^0
166 @			.2626107E-05	-.5842526E-05	.3216419E-05
167 @			-.1247760E-04	.1306251E-04	-.2558662E-04
168				.1083887E-05	-.1083887E-05
169 @			.3625232E-06	-.7250464E-06	.3625232E-06
170 @			.2626107E-05	-.5842526E-05	.3216419E-05
171 @			-.1247760E-04	.1306251E-04	-.2558662E-04
172				.1083887E-05	-.1083887E-05
173 @			.3625232E-06	-.7250464E-06	.3625232E-06
:			:	:	:
4457				.1349235E-16	-.1248992E-14
4458				.6268719E-18	-.6749289E-18
4459				-.4199276E-28	.4199276E-28
4460				.3748097E-18	-.9455578E-18
sum1	-.52754E-37	.30729E-36	-.29743E-36	-.91553E-26	-.18099E-04
max	.62693E-37	.94040E-37	.12478E-04	.13063E-04	.32607E-04
cnt	0	0	30	364	

ee→eeH

M_H=120GeV





$$\Delta r = 2.55\%$$

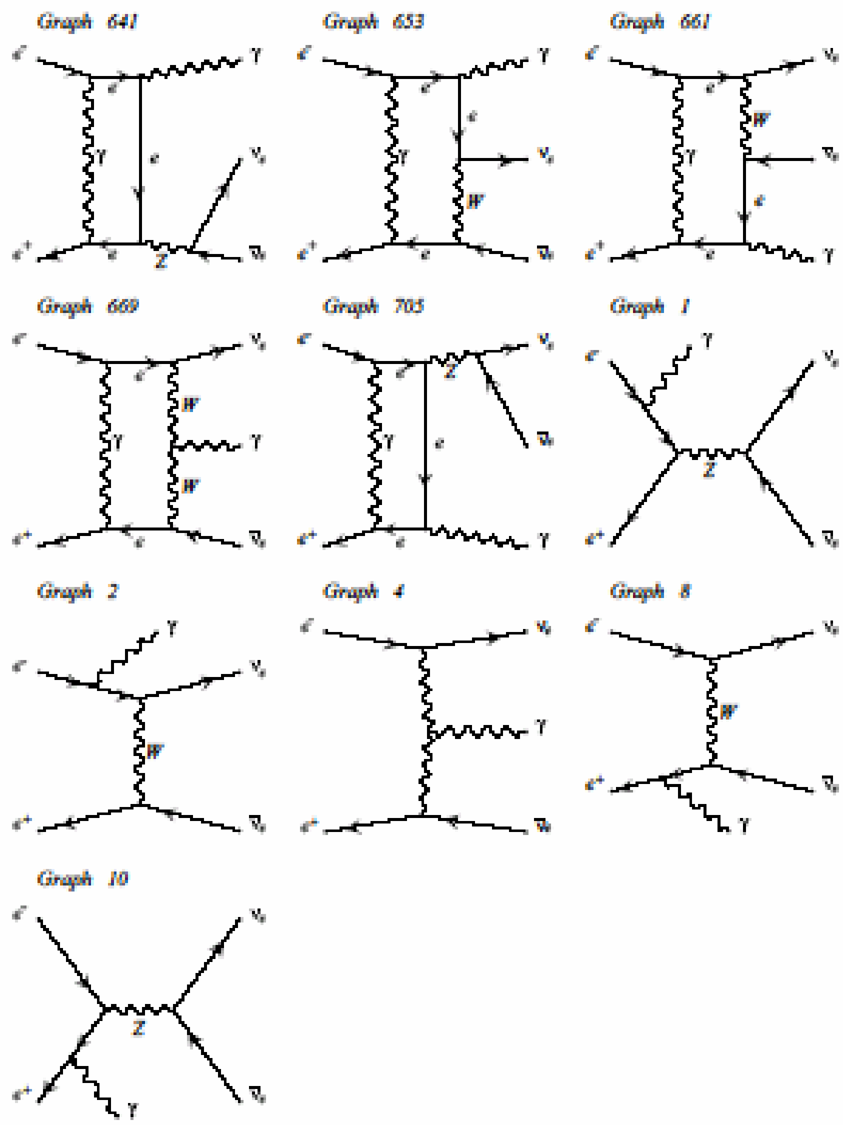
$e^+e^- \to \nu\bar{\nu}\gamma$

- diagrams
  full set (for NLG check)
      tree 10, 1-loop 1099 (inc. C.T.)
  production set (for integration)
      tree 5, 1-loop 331 (inc. C.T.)
- M_W= 80.3766 GeV , M_Z= 91.1876 GeV
  Γ_Z= 2.4956 GeV
  M_H= 120GeV, m_t = 174GeV
  E_{CM}= 200 ~ 3000 GeV
  OPAL cut: (γ)p_T>0.05E_B, 15° < θ <165°

$$e^+e^- \to \nu\bar{\nu}\gamma$$

IR diagrams

tree diagrams

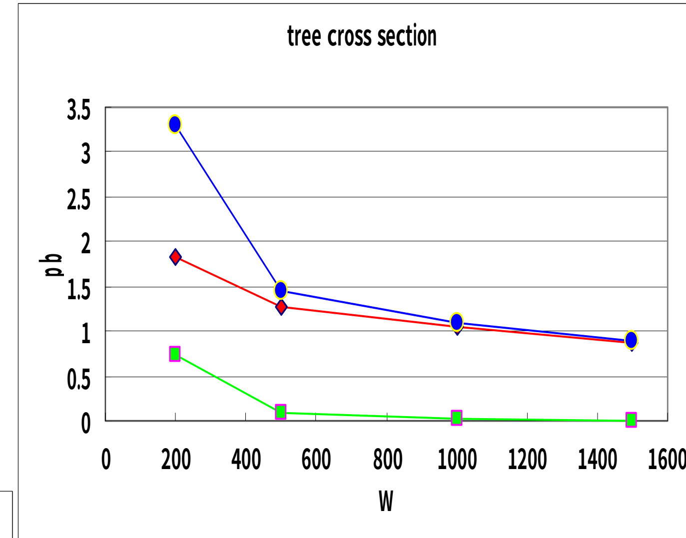


check by NLG (ee→nunuA)

	a^4	a^3	a^2	a^1	a^0
1V				-.5252278E-03	.7952048E-03
2V				.1872623E-14	-.1872623E-14
6V				.1872623E-14	-.1872623E-14
⋮					
18V			.4986017E-11	.7865753E-10	-.8364354E-10
19V			.3779384E-10	.1104061E-09	-.1482000E-09
20V			.1208277E-10	-.2416554E-10	.1208277E-10
22V				.6561564E-10	-.6561564E-10
23V				-.4995059E-42	.4995059E-42
24V			.4797596E-09	-.9595192E-09	.4797596E-09
26V				-.6561564E-10	.6561564E-10
27V				.4995059E-42	-.4995059E-42
28V			-.4797596E-09	.9595192E-09	-.4797596E-09
29V-	-.4773915E-37	.2482467E-36	.5633036E-36	-.7638111E-36	-.1405948E-07
30V-	-.7346840E-39	.4897893E-39	.3673420E-38	-.3428525E-38	.5827357E-08
31V-	-.1040802E-37	.9896805E-37	.1900383E-36	-.2785983E-36	-.1405949E-07
⋮					
854P				-.1180226E-14	.1180226E-14
855B			.7634114E-04	-.3060816E-03	.8768512E-03
sum1	.14148E-30	-.40640E-30	-.86324E-25	.17416E-23	.51997
max	.12998E-30	.32070E-04	.96820E-04	.59183E-01	.15505
cnt	15	25	70	381	

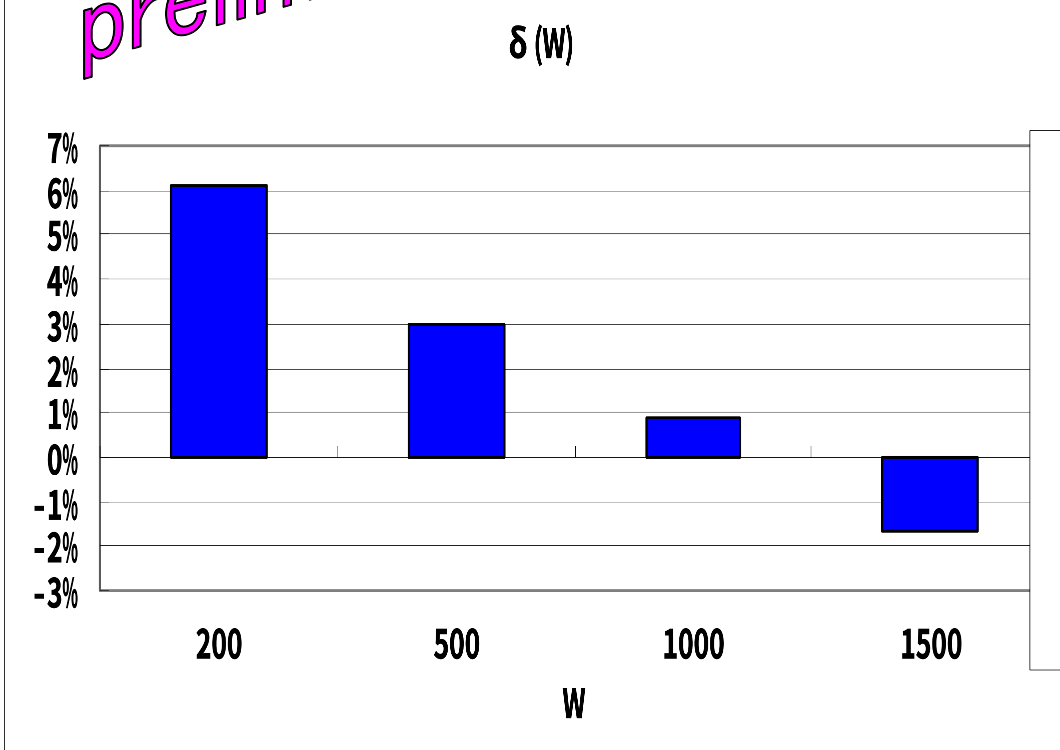
$\tilde{\alpha}$

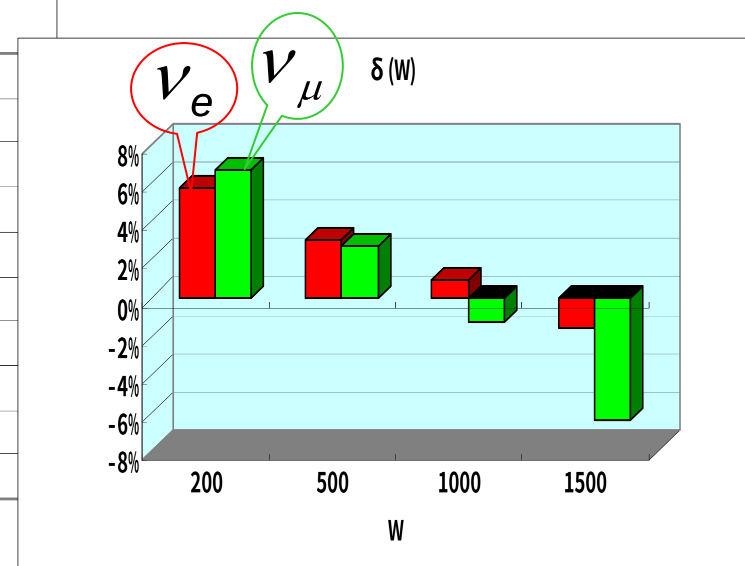
$$e^+e^- \to \nu\bar{\nu}\gamma$$



preliminary

M_H=120GeV





$$\Delta r = 2.55\%$$

conclusion

- Technology is established to handle full-EW RC for 2→3 processes.
- Gauge parameter independence in NLG is powerful to confirm the results.
- New results for full EW correction is obtained for

$$e^+e^- \to e^+e^-H, \nu\bar{\nu}\gamma$$